Dual thinking for scientists

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Abstract: Recent studies provide compelling evidence for the idea that creative thinking draws upon two kinds of processes linked to distinct physiological features, and stimulated under different conditions. In short, the fast system-I produces intuition whereas the slow and deliberate system-II produces reasoning. System-I can help see novel solutions and associations instantaneously, but is prone to error. System-II has other biases, but can help checking and modifying the system-I results. Although thinking is the core business of science, the accepted ways of doing our work focus almost entirely on facilitating system-II. We discuss the role of system-I thinking in past scientific breakthroughs, and argue that scientific progress may be catalyzed by creating conditions for such associative intuitive thinking in our academic lives and in education. Unstructured socializing time, education for daring exploration, and cooperation with the arts are among the potential elements. Because such activities may be looked upon as procrastination rather than work, deliberate effort is needed to counteract our systematic bias.

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Perspective, part of a Special Feature on Reconciling Art and Science for Sustainability

Dual thinking for scientists

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ABSTRACT. Recent studies provide compelling evidence for the idea that creative thinking draws upon two kinds of processes linked to distinct physiological features, and stimulated under different conditions. In short, the fast system-I produces intuition whereas the slow and deliberate system-II produces reasoning. System-I can help see novel solutions and associations instantaneously, but is prone to error. System-II has other biases, but can help checking and modifying the system-I results. Although thinking is the core business of science, the accepted ways of doing our work focus almost entirely on facilitating system-II. We discuss the role of system-I thinking in past scientific breakthroughs, and argue that scientific progress may be catalyzed by creating conditions for such associative intuitive thinking in our academic lives and in education. Unstructured socializing time, education for daring exploration, and cooperation with the arts are among the potential elements. Because such activities may be looked upon as procrastination rather than work, deliberate effort is needed to counteract our systematic bias.

INTRODUCTION

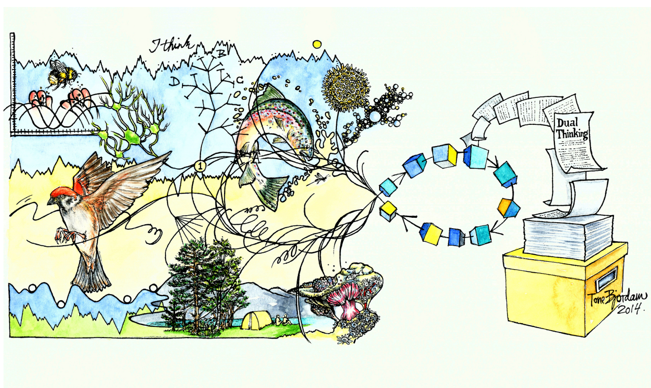
For centuries, intuition and reasoning have been recognized as different elements of human thought (Glatzeder 2011) but the work in this field long remained rather descriptive. Recently, however, there has been a surge of experimental work supporting the view that there are in fact two intimately linked yet distinct modes of thinking, fulfilling complementary roles in cognition (Baas et al. 2008, Morewedge and Kahneman 2010, Allen and Thomas 2011, Glatzeder 2011). Although there are many subtleties to the two "modes," "processes," or "systems," most authors converge on the recognition of a dichotomy between them as well as on their main characteristics: System-I could be called intuition. It works largely unconsciously and relies on instantaneous underlying associations. System-II could be called reasoning and relies on the much slower process of reasoning (Fig. 1). A compelling account of the strengths and weaknesses of the two modes is given by Nobel laureate Daniel Kahneman in his recent book *Thinking Fast and Slow* (Kahneman 2011), showing among other things that we systematically overestimate the role of rationality (system-II) in our decision making.

Here we will defend the perhaps provocative view that the way science and its institutions are organized reflects this overestimation of system-II thinking in producing scientific progress. We briefly summarize key insights from the rapidly unfolding field of cognitive science, and discuss how those could be used to rethink conditions for catalyzing scientific breakthrough. A short version of the argument we lay out has been published earlier as an opinion piece in *Proceedings of the National Academy of Sciences* (Scheffer 2014).

The associative machine

Although we still do not know how cognition works mechanistically in our brains, it has become clear that system-I may be characterized as an "associative machine." Experiments

Fig. 1. The process of dual thinking as envisioned by the Norwegian artist Tone Bjordam (http://www.tonebjordam.com/). Although the systematic reasoning process (system-II) depicted in the right-hand loop is emphasized in the way we teach science and organize our work, the associative left-hand loop (system-I) of the dual thinking process is usually hidden (Scheffer 2014). We argue that the working of this generator of novel ideas has always been essential for scientific breakthroughs and should be taught and catalyzed more explicitly in academia.



reveal that ideas, a term used here broadly to include all kinds of concepts, are linked in our brain through a web of associations. For instance, "banana" is linked to "fruit," to "yellow," to a taste, etc. Triggering one idea activates the associated ones causing decaying ripples of subsequent associations through the web. As coherent ideas mutually stimulate each other, there is positive feedback and a tendency for coherent subwebs to be activated as a whole.

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A major breakthrough in research on this associative machine came with the development of tests that measure how easily persons retrieve “remote” associations between concepts. High scores on such association and divergent thinking tests are often associated with “creativity,” a term reserved more precisely for the production of ideas that are not only original but also useful, thus excluding nonsense associations (Csikszentmihalyi 1999). The quantification of differences in associational capacity between persons allows the search for an underlying physiological basis. For instance, recent work has shown that persons who are good at divergent thinking tests, tend to have lower than normal dopamine-D2 receptor densities in their thalamus, suggesting that associative capacity is related to thalamocortical information flow (de Manzano et al. 2010). Interestingly, schizophrenia is linked to even lower thalamic D2 receptor densities, placing creative persons on a gradient between normal and schizophrenic individuals. This idea is reinforced by work showing that spontaneous eye-blink frequencies of individuals that score high on divergent thinking tests tend to fall between those of normal and schizophrenic persons (Chermahini and Hommel 2010). The latter group is plagued by a flow of bizarre associations. Assuming that the thalamus serves as part of a filtering system that keeps thought into a “box” of relevant association, one could speculate that “thinking outside the box might be facilitated by having a somewhat less intact box” (de Manzano et al. 2010).

The right state of mind

Of interest from our current practical perspective is the finding that the same person can be better or worse at finding remote associations depending on her state of mind. For instance, a cheerful state (Baas et al. 2008) and mind-wandering (Schooler et al. 2011) tend to be conductive to finding novel associations. Many everyday life observations fit with the idea that creative ideas come more easily under particular conditions. For instance, some people find that they get ideas especially under the shower or while walking. Perhaps the best-known example is Charles Darwin, who had a special thinking path, “the sandwalk,” where he used to walk round after round to promote his thought. Also, insights may appear in a mind that is dozing off. A famous example is the chemist August Kekulé who after thinking intensely about the seemingly insolvable question of what the structure of a benzene molecule could be, fell asleep in his chair at the fire place and woke up with the revolutionary idea of a circular structure linked to a dreamy vision of a snake biting its own tail (Gratzer 2004). The tremendous significance of such insights for science is illustrated by the reaction of the Nobel laureate in chemistry Adolf von Baeyer to Kekulés eureka findings, stating that he would have exchanged his lifetime’s accomplishments for this one insight Kekulé got from his dream (Gratzer 2004). This underlines the relevance of the question how the intuitive system-I thinking might be offered a more prominent place in scientific labor.

Having the elements in place

Because associative capacity is influenced by the state of mind, an obvious element would be to deliberately plan moments of favorable conditions tailored to boost association. However, there is clearly another major aspect to consider: one can only associate between available elements. Darwin could generate his insights while walking, only because he had his mind loaded with a rich array of observations and ideas. Similarly, Kekulé got his dreamy strokes of insight only after long days of thinking about bits and pieces of the puzzle he tried to solve. As he recalled, he actually saw partial structures swirling around in his mind’s eye, as he dozed away before they finally fell into place (Gratzer 2004).

These anecdotes also illustrate another relevant component when it comes to preparing the mind for novel associations: “priming.” Associations are made more readily between elements that have been (unconsciously) primed by recent thoughts or observations (Morewedge and Kahneman 2010, Kahneman 2011). For instance, subjects primed with the concepts of washing or dirtiness are more likely to complete the letter combination SO_P as SOAP, whereas priming with concepts related to food would more easily complete the ambiguous letter combination as SOUP. Clearly, the available set of ideas defines the playing ground for creative associations, but priming subsets may steer the mind to centers of gravity for such association.

Balancing the dual thinking

We have so far focused on the question how system-I could be stimulated. However, good science obviously needs a heavy contribution from the reasoning system-II, because the intuitions from system-I are all too often wrong in the hindsight. Recalling the definition of creativity as the generation of novel useful ideas, the best results are obtained by an intimate tango between the two systems, and there are many examples of well-known scientists who seem to have taken this approach almost deliberately. For example, as one of us (MS) discussed the ideas we expose here with Kenneth Arrow, the youngest winner of the Nobel Memorial Prize in economics and known for several revolutionary contributions to the field afterwards, Arrow stated: “If you are not wrong two thirds of your time, you are not doing very well; and if you are wrong you better find out yourself. Not only because it is more pleasant, but also because it helps you to learn.” This reflects a remarkable similarity to the style of Richard Feynman, the extraordinarily innovative Nobel Laureate in physics. He was widely considered the most original mind of his generation (Gleick 2011). Feynman’s famously productive intuition was often wrong, and he did spend a substantial amount of time going down what later turned out to be dead ends (Gleick 2011). Only by balancing the intuitions by his formidable system-II did Feynman create a series of breakthrough ideas in physics.

Avoiding the islands of insight

Feynman had a broad interest within and beyond science. However, despite his unbridled curiosity, he somehow deliberately tried to stay away from knowing previous explanations. He read little of the contemporary literature, and refused to follow the standard paths to which conventional mathematical notation would take him (Gleick 2011). The blinding effect of dogma was identified as a main inhibitor of scientific progress already in the 16th century by Baruch Spinoza. However, the forces that attract one to existing points of view are strong. One easily falls in love with a hypothesis, and such love is blinding when it comes to observations that fail to fall in harmony (Chamberlin 1897). In addition, it could be argued that the classical machinery of hypothesis testing and refining tends to draw scientific enquiry into ever smaller circles around existing foci of interest, at the risk of creating islands of insight in a largely unexplored sea of ignorance.

Enabling dual thinking

The new insights in the machinery of cognition and the examples of scientific breakthrough thinking suggest some elements of an answer to our question, how scientists and scientific institutions might make best use of dual thinking. Of course Darwin, Kekulé, and Feynman were exceptional minds, and our aim is not to ask how such minds and earth-shaking breakthroughs could be recreated. However, also on more modest scales, eureka moments are the sparks that catalyze many jumps in scientific insight. Importantly, such jumps may often imply that an association had been missing in scientific thinking, and a reshuffling of the world image was in fact overdue. The practical question we wish to address is: How could scientists and their institutions think of ways to promote such novel insightful associations, and thus allow for more frequent reorganizations of our scientific worldviews? We neither pretend to have anything close to a "silver bullet" approach, nor wish to review the extensive literature on promoting creativity in general. Instead, we propose some ingredients that emerge from the material we presented, and, as science practitioners, make sense to us as elements worth considering when it comes to planning the everyday dynamics of science and education.

Emptying time

Generally accepted elements of working in science are spending time behind a computer or the lab and having meetings in the office. Less easily accepted as productive work are activities such as dozing in an armchair or taking a stroll in the woods. But this perception may be wrong. Darwin's deliberate walks and Kekulé's naps resonate with the common experience that an insight in our work questions may often come outside the office rather than sitting behind a desk. Also, in our experience crucial discussions at meetings frequently happen on a walk with colleagues in the break. This suggests that it might be a good idea to deliberately plan substantial unstructured time and breaks to create moments of reflection. We could for instance set aside part of our working time for reflective walks, be it with colleagues and students or alone. Also, at workshops planning, say, 50% of informal reflection time might often be more productive than spending full days in the meeting room.

Diversifying inputs

Although solitude is obviously crucial for the scientific mind to work, exposure is the other essential element. A large breakthrough in science often comes from a novel connection between existing but thus far isolated ideas. This can only happen in a mind that has been exposed to such remote lines of thought. Indeed science historian Rogers Hollingsworth found that this is the case systematically for the kind of work that results in Nobel, Lasker, or Crafoord prizes, stating that "Without any exceptions, over the past century the lead scientist on any major discovery has internalized a great deal of scientific diversity" (Whitfield 2008:872). Such diversity of information can be found in the literature and on the Internet. On the other hand informal discussions with people from other scientific backgrounds may put one on the track of an unexpected potential link. Much has been written about the conditions for such cross-disciplinarity to happen, and it turns out that "having something click" on a personal level is essential, but also that encounters, e.g., at informal places with food and drinks, are often a starting point, suggesting that some social engineering might be less complicated than it seems (Whitfield 2008). Obviously, curiosity is a matter of attitude, and could be stimulated more in scientific education. As an antidote to an overly focused curriculum we could use another quote from our conversation with Kenneth Arrow as a motto: "It is so far from anything I do, I must be interested."

The arts as a partner

Although connecting between remote branches of science is a somehow broadly accepted goal, the evidence we exposed suggests that we may want to pay more attention to facilitating the conditions that catalyze the process for remote ideas to actually fall into place, and to actively create the space for that. Also, it may be worth connecting in a more structural way to thinkers outside science. Research suggests that a randomly assembled group of people may often be better at solving complex problems than a selection of experts (Page 2008, Lorenz et al. 2011). This "wisdom of the crowds" effect is due to the fact that experts tend to be good, but also relatively similar in their thinking and therefore less likely to cover the broad set of views one gets from a random and therefore more diverse group.

A group that is focused on novelty and creativity but is also quite complementary to scientists are the artists. Some quotes from renowned scientists, collected by Robert S. Root-Bernstein (Root-Bernstein 2000), may illustrate this science-arts complementarity. Mitchell Feigenbaum, the famous pioneer of chaos theory states: "It's abundantly obvious that one doesn't know the world about us in detail." "What artists have accomplished is realizing there's only a small amount of this stuff that's important, and then seeing what it was. So they can do some of my research for me." This is nicely complemented by the vision of C. S. Smith of MIT stating: "I have slowly come to realize that the analytic, quantitative approach I had been taught to regard as the only respectable one for a scientist is insufficient." "The richest aspects of any large and complicated system arise from factors that cannot be measured easily, if at all. For these, the artist's approach, uncertain though it inevitably is, seems to find and convey more meaning."

Clearly, artists have a way of extracting meaningful aspects of the complex world around us that is quite complementary to what scientists tend to do, and may thus help map some of the "sea of ignorance" when it comes to finding interesting input for our hypothesis testing machinery. Also, although training in science is largely focused on skills reducing the risk of mistakes, training in arts often centers on controlled risk taking as a means to stimulate innovation. Could science do with some more of that? Certainly this would fit with the anecdotal observation that Richard Feynman spent much of his time venturing in dead alleys, and with the view of his fellow Nobel laureate Kenneth Arrow that a scientist is not doing very well if he is not wrong two thirds of the time. Perhaps we should use some of the education techniques from arts to boost adventurous exploration and "learning at the edge of chaos" (Bertschinger and Natschläger 2004, Kleiman 2011)? Certainly the provocative idea that a closer arts-science connection could catalyze breakthrough science (Gurnon et al. 2013) is in line with the curious fact that Nobel laureates are more likely to pursue artistic endeavors than are members of the Royal Society and National Academy of Sciences, who are in turn more artistically engaged than the "average" scientist (Root-Bernstein et al. 2008).

The idea that mind wandering should be considered part of the scientific method, that we should educate for risk-taking exploration, or that arts may help the sciences, might well meet with skepticism in practice. However, the evidence is overwhelming that such seemingly irrelevant activities should not be seen as procrastination, but rather as effective ways to boost scientific productivity.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/issues/responses.php/7434

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